A Methodology to implement Process-Based Manufacturing Cost Models Into The Traditional Performance-Focused Multi-Disciplinary Design Optimization

Contributors:

H. P. Bao*, H. J. Dunn**,

J. L. Rogers**, J. A. Samareh**

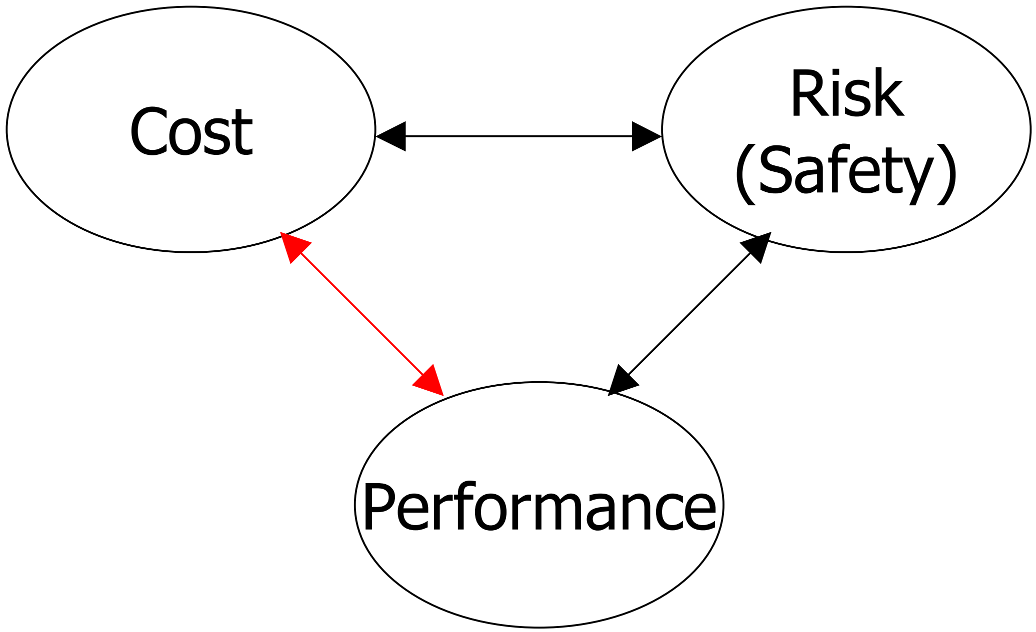
*Old Dominion University

** MultiDisciplinary Optimization Branch (MDOB), NASA Langley Research Center

Overview

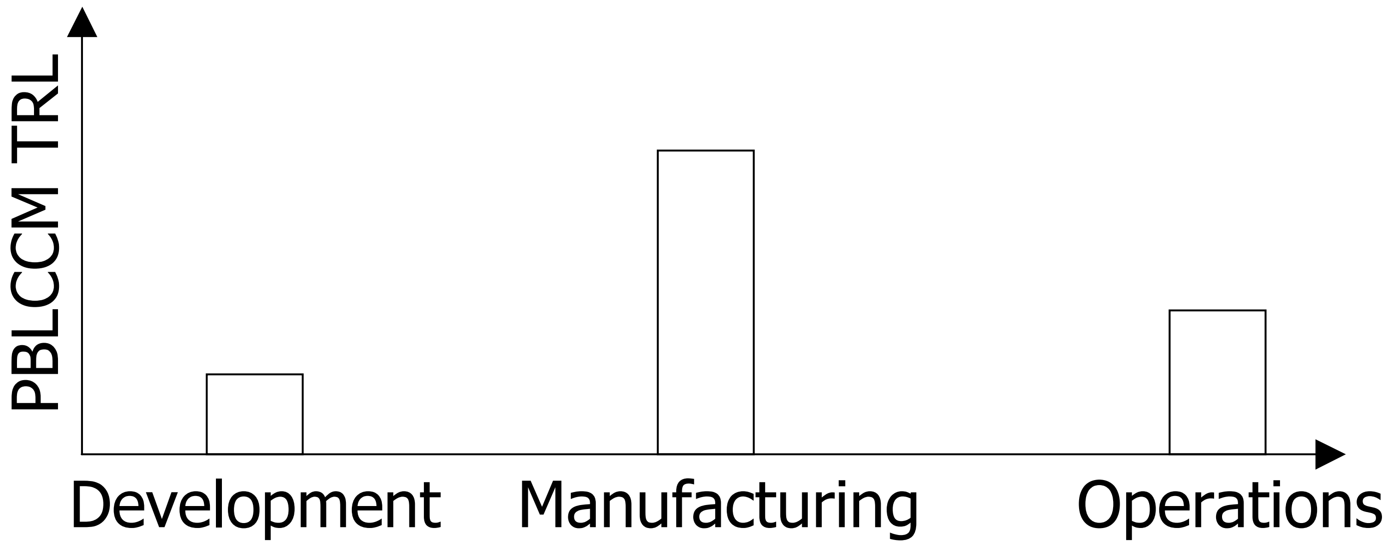
- Design Space
- Process-Based Life Cycle Cost Modeling (PBLCCM)
- Cross-platform implementation
- Optimization using genetic algorithm (GA)

Design Space



We plan to focus on the use of process-based cost modeling in design and optimization.

Process-Based Life Cycle Cost Modeling (PBLCCM)



We believe the lessons learned in the process-based cost modeling (PBCM) for manufacturing will be applicable to other disciplines when their PBCM are matured.

Cost Consideration

- In the past cost was derived from structural Weight.
- Current cost modeling tools allow process-based manufacturing and Assembly costs (PBMAC) of aircraft to be included in the conceptual design phase
- MDOB has demonstrated the use of a PBMAC modeling tool with a performance analysis tool for cost-performance optimization (AIAA 2000-4839)

Cost Models

1. Learning Curve:
   - Basic Tenet: There is a relatively constant percentage reduction in the cost, or man-hour, for doubled quantities of production

Examples of Power Law Models

- From ACCEM applied to hand lay-up:
  - Position template and tape down:

$$0.000107 \ \ area^{0.77006}$$

  - 12 in. manual ply deposition:

$$0.05 + plies\,(0.001454\, length^{0.8245})$$

  - Transfer layup to curing tool:

$$0.000145 * (area)^{0.6711}$$

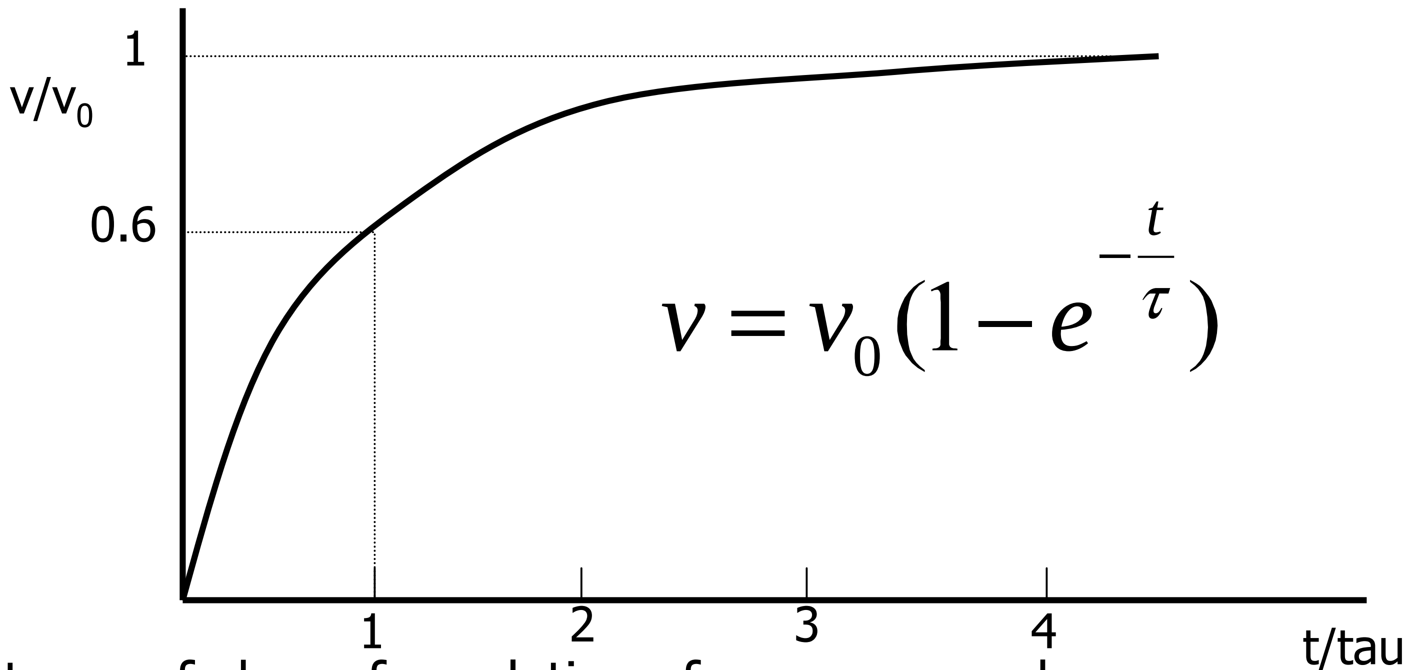
  - Stretch flange:

$$plies * (length * 0.064 * radius^{-0.5379} * flange^{0.7456})$$

First Order Velocity Model

- Background:
  - NASA/Boeing Advanced Technology Composite Aircraft Structures (ATCAS) Initiative (Contract NAS1-18889)
  - MIT's Laboratory for Manufacturing and Productivity
  - Ph.D. Thesis :"Adaptive Framework for Estimating Fabrication Time", E.T. Neoh, MIT 1995

First Order Velocity Response

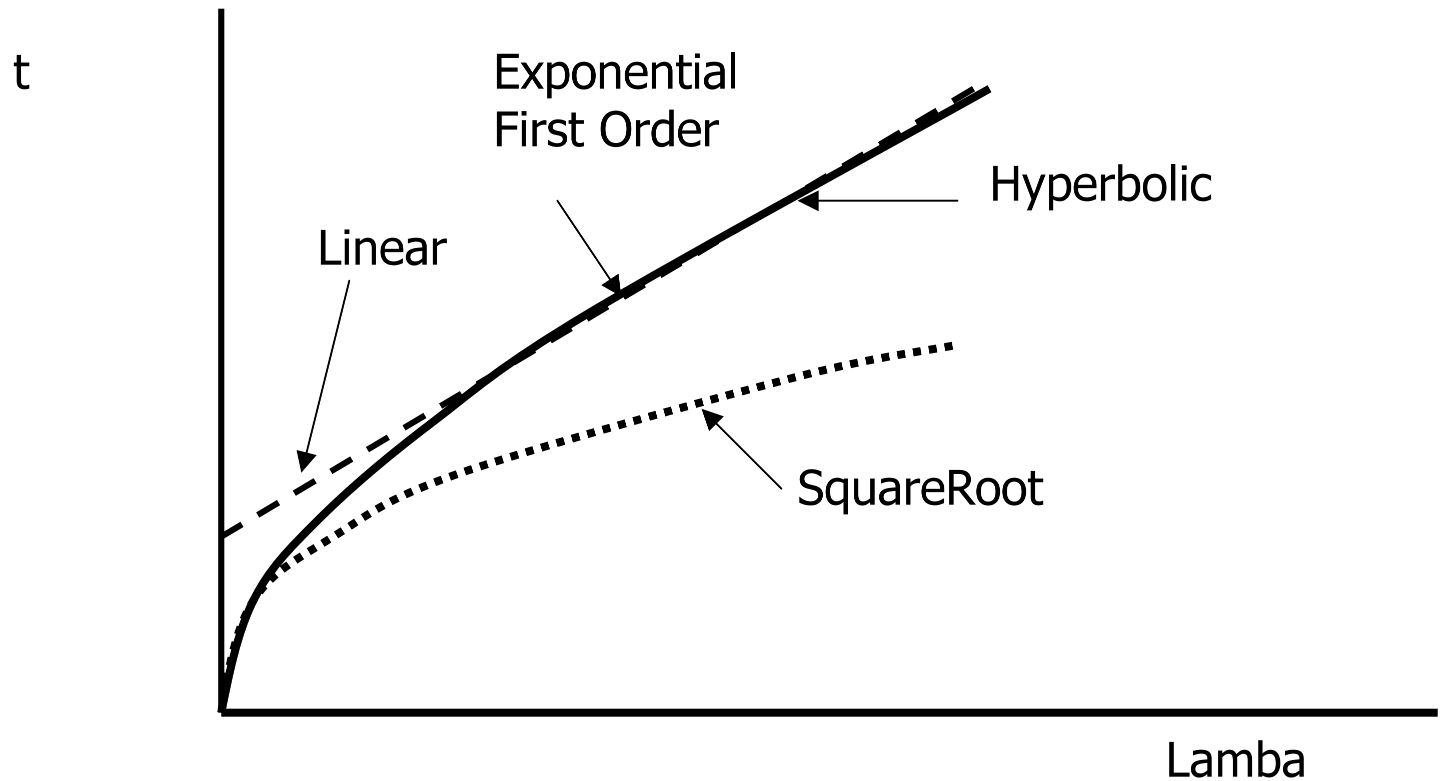


$$v = v_0(1 - e^{-\frac{t}{\tau}})$$

- Advantages of above formulation of process speed:
  - Amenable to physical modeling
  - V_0 and Tau have meaningful physical interpretation

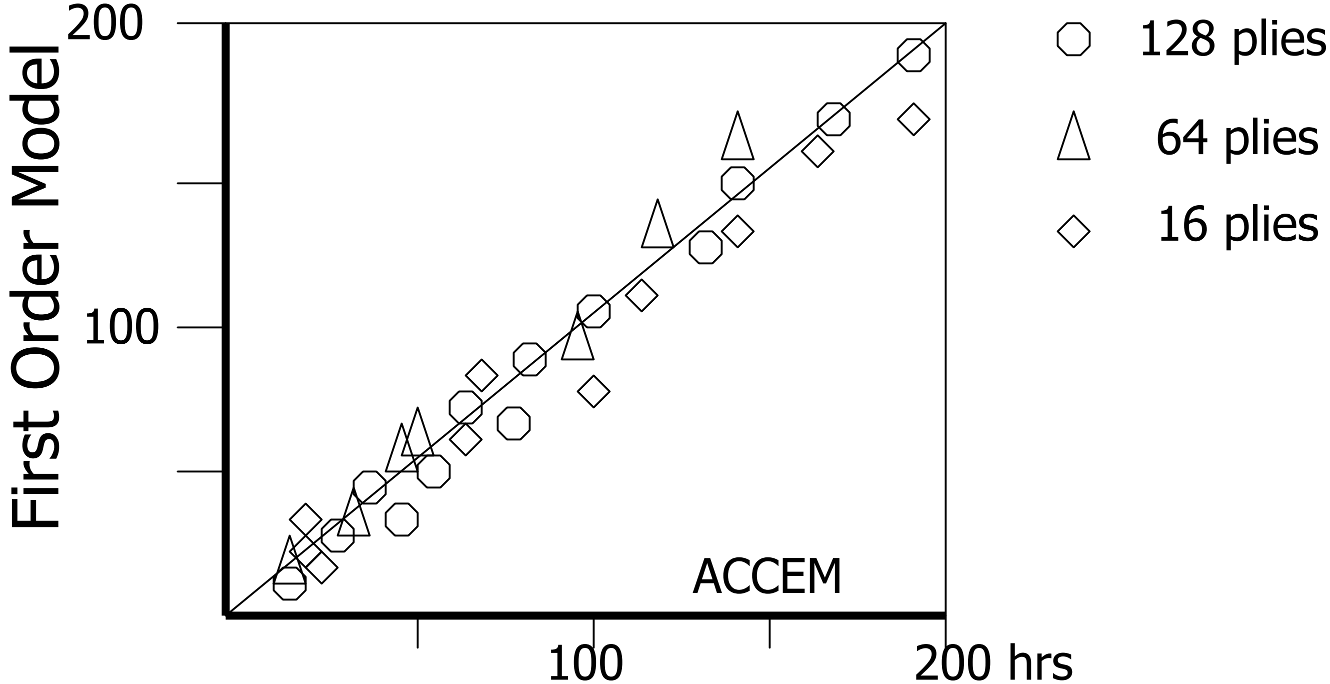
First Order Model (Continued 1)

- The three approximations to the Exponential First Order equation:



First Order Model (Continued 2)

- Validation of Model (Neoh 95):



Comparison between First Order and ACCEM for Hand Layup

First Order Model (Continued 3)

- Sample Process time estimation:

Process	Tau	V_0	Design Feature
Hand lay-up 3 ″tape	0.0191 hrs	10950 in/hr	Length
Hand lay-up 12″ tape	0.0111 hrs	1896 in/hr	Length
Hand lay-up woven tape	0.0856 hrs	57500 in^2/hr	Area
Disposable bagging	0.0331 hrs	5137 in^2/hr	Area
Reusable bagging	0.0092 hrs	6219 in^2/hr	Area

First Order Model (Continued 3)

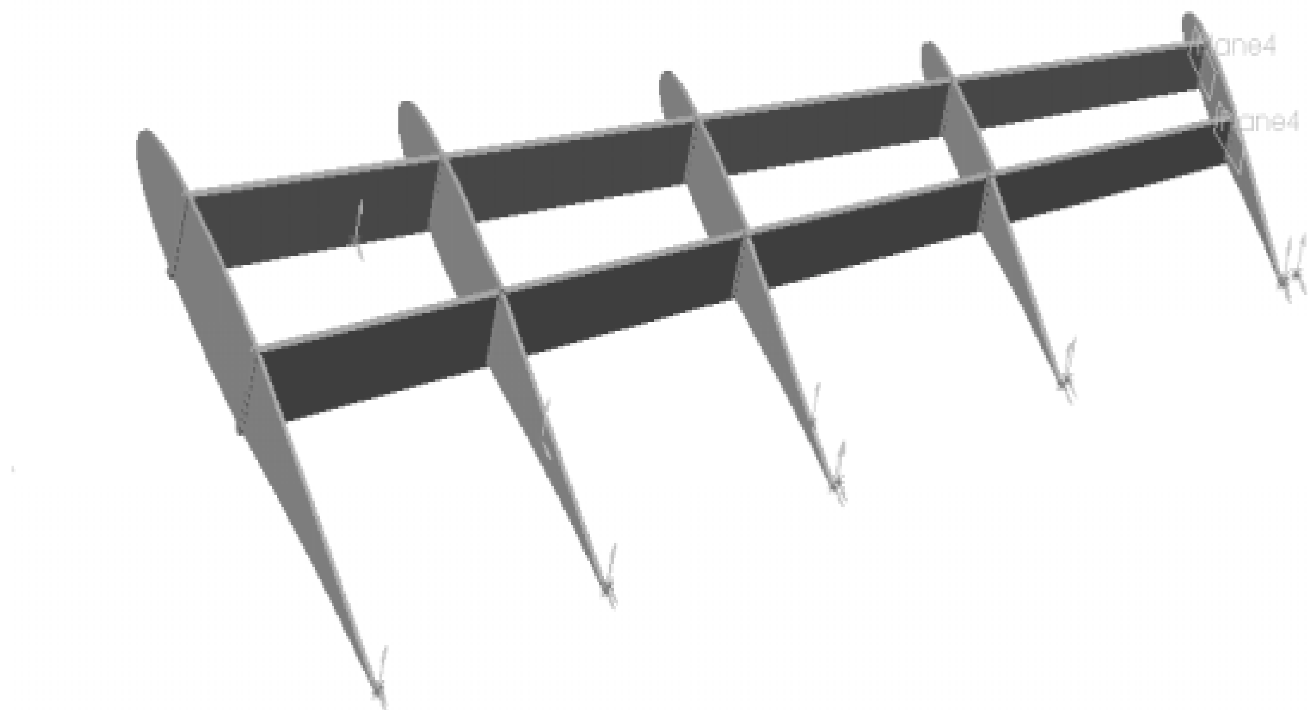
- Estimation of process time for commercial airframe structures:

Material	Item	V_0	Tau, min	Design feature
Aluminum	Skin Fabrication	3.024	3.1123E+04	Wetted area, in^2
	Rib Fabrication	2.059	4.1423E+04	Wetted area, in^2
	Spar Fabrication	2.462	3.6934E+04	Wetted area, in^2
	Wing Assembly	0.0395	2.1341E+04	Perimeter, in
Composite	Skin Fabrication	2.1447	4.3883E+04	Wetted area, in^2
	Rib Fabrication	0.8236	1.0356E+05	Wetted area, in^2
	Spar Fabrication	1.4485	6.2788E+04	Wetted area, in^2
	Wing Assembly	0.02826	2.9877E+04	Perimeter, in

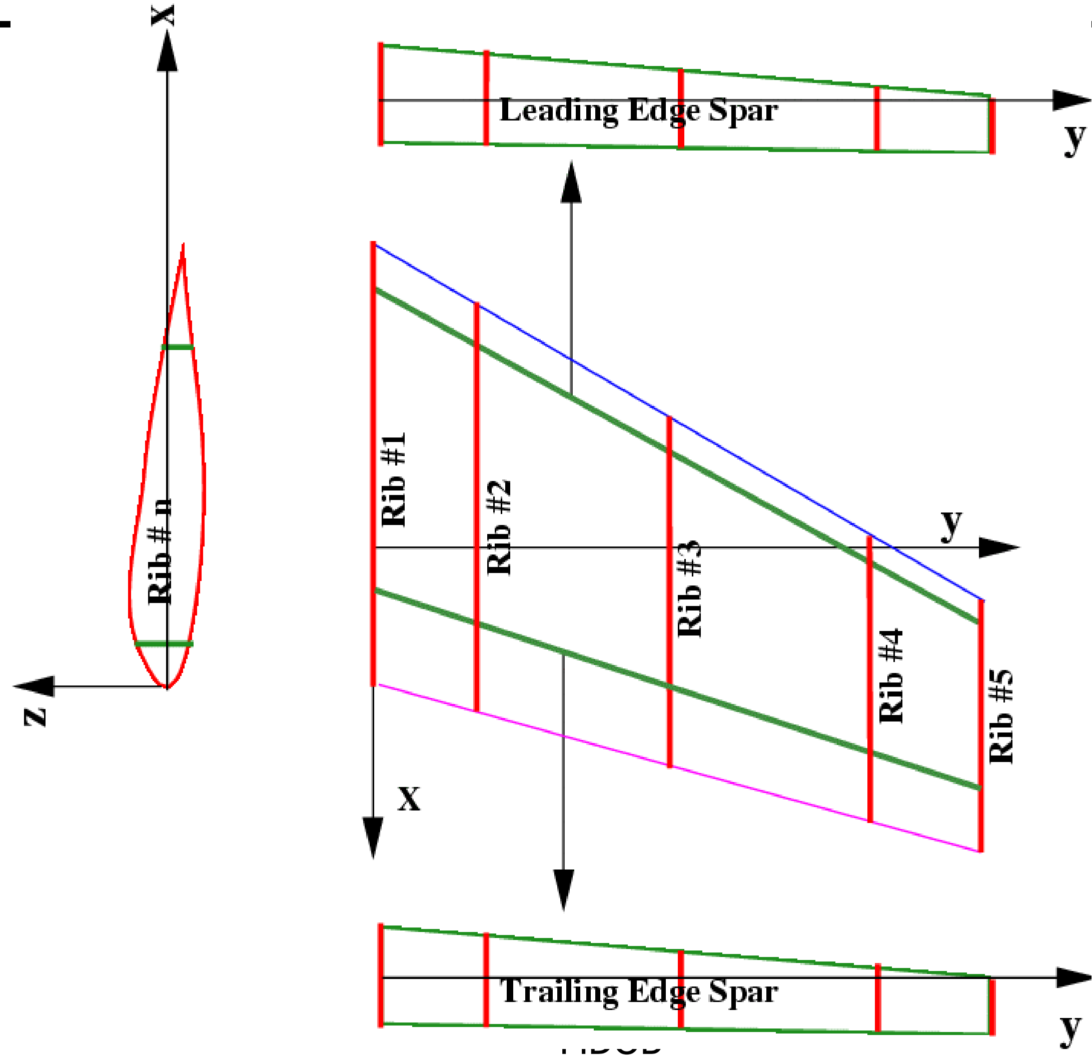
First Order Model (Continued 4)

- Cost Estimation of Generic wing
  - Physical elements:
    - Front and Rear spars
    - Five ribs
    - Skins
  - Process Costs Include:
    - Fabrication of Spars
    - Fabrication of Ribs
    - Fabrication of Skins
    - Assembly of Spars, Ribs, and Skins into Wing

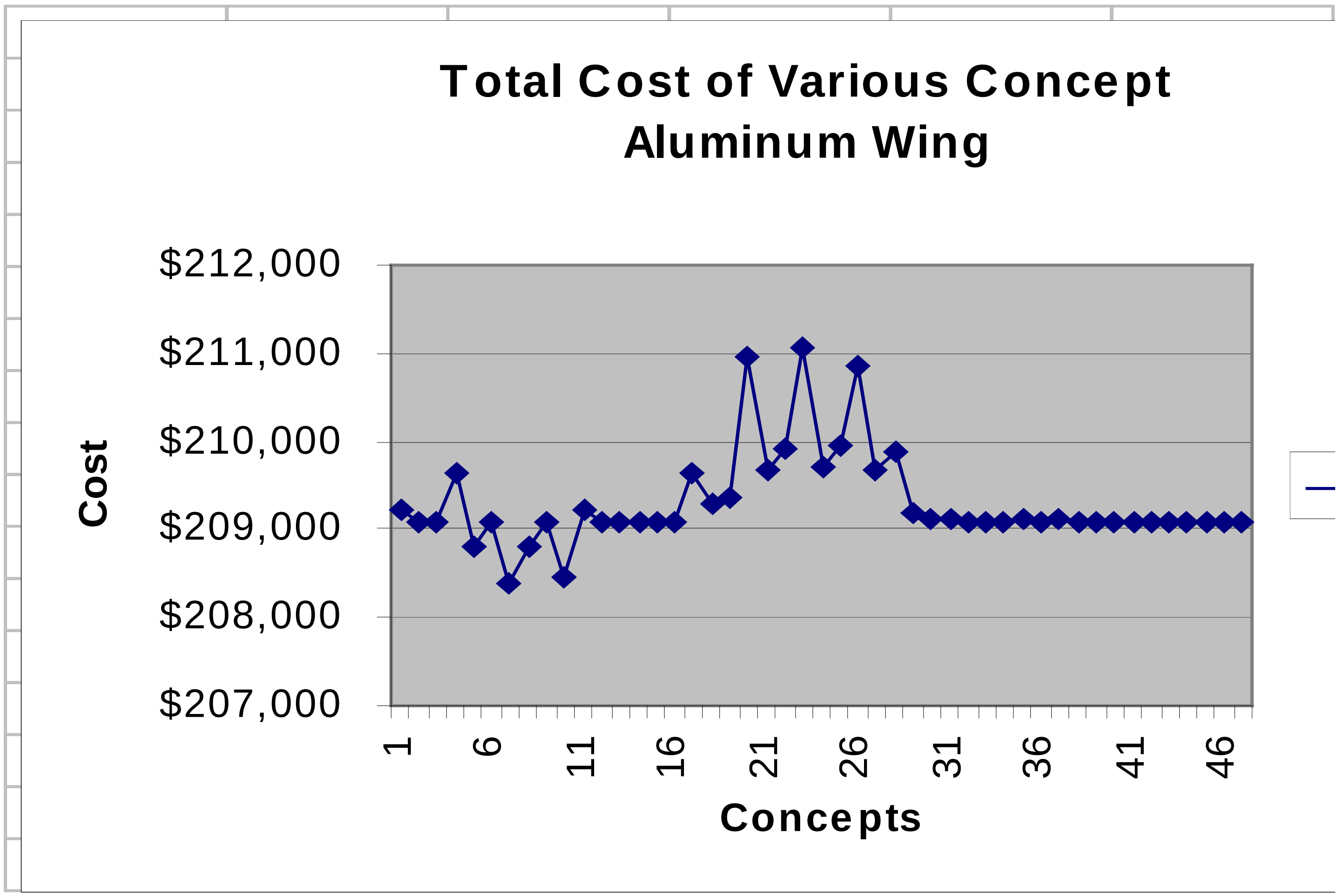
Cost Estimation of Generic Wing: Solid Model



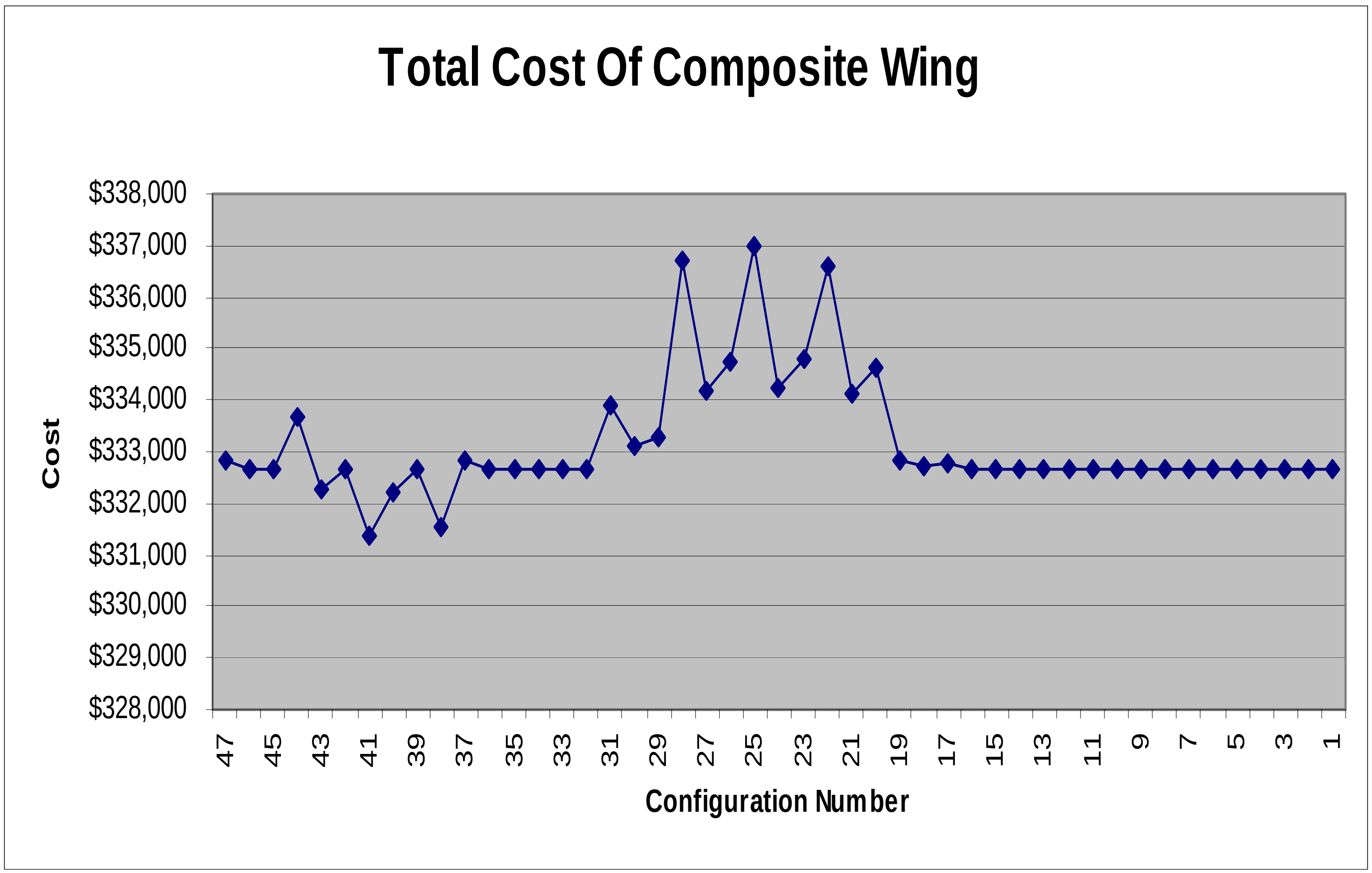
Cost Estimation of a Generic wing:Parametric Model



Cost Estimation of a Generic Wing: Aluminum

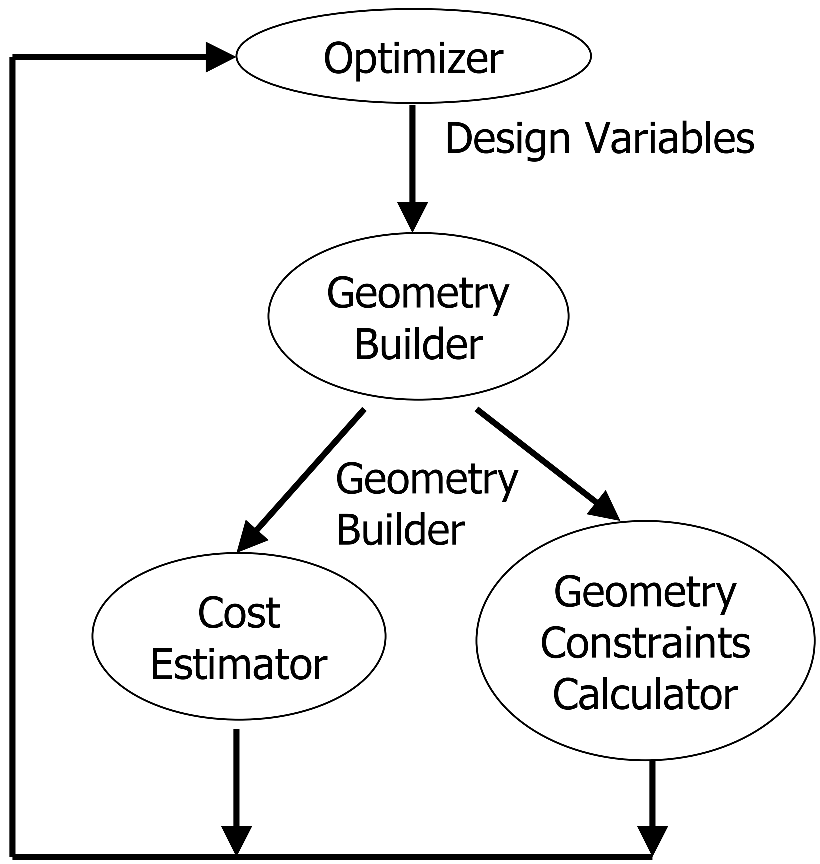


Cost estimation of a Generic Wing: Composite Material

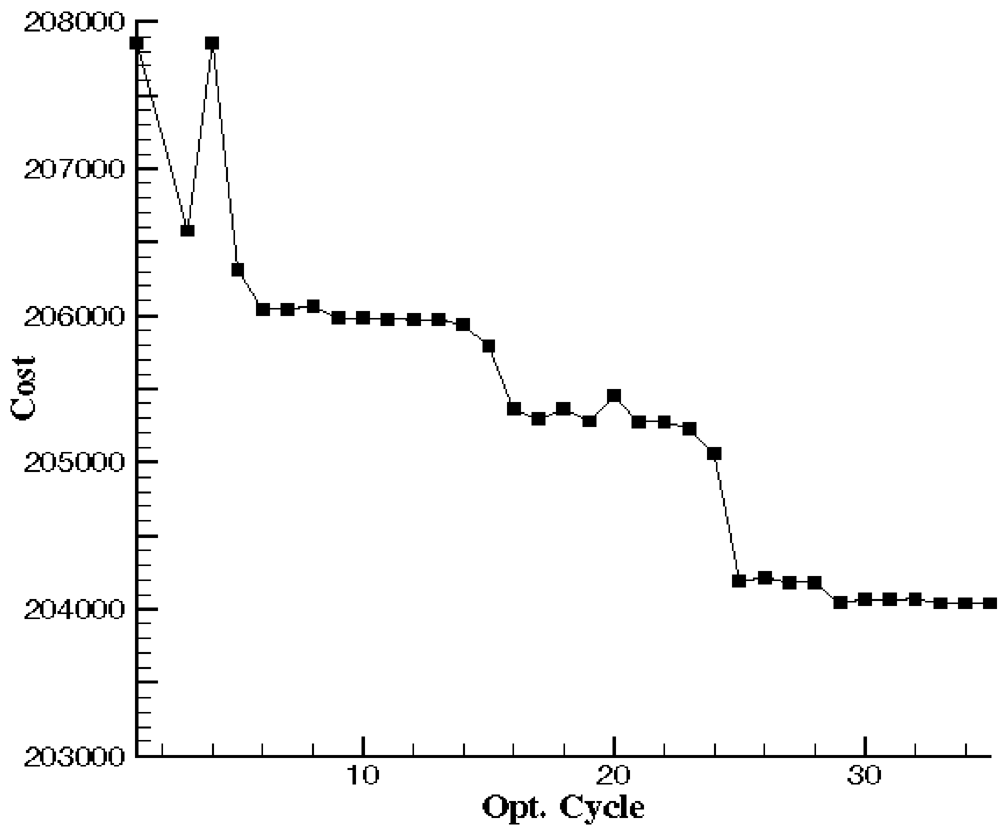


Cost Optimization Process

- Diagram



Cost Estimation of a Generic wing: Optimization for Aluminum Wing



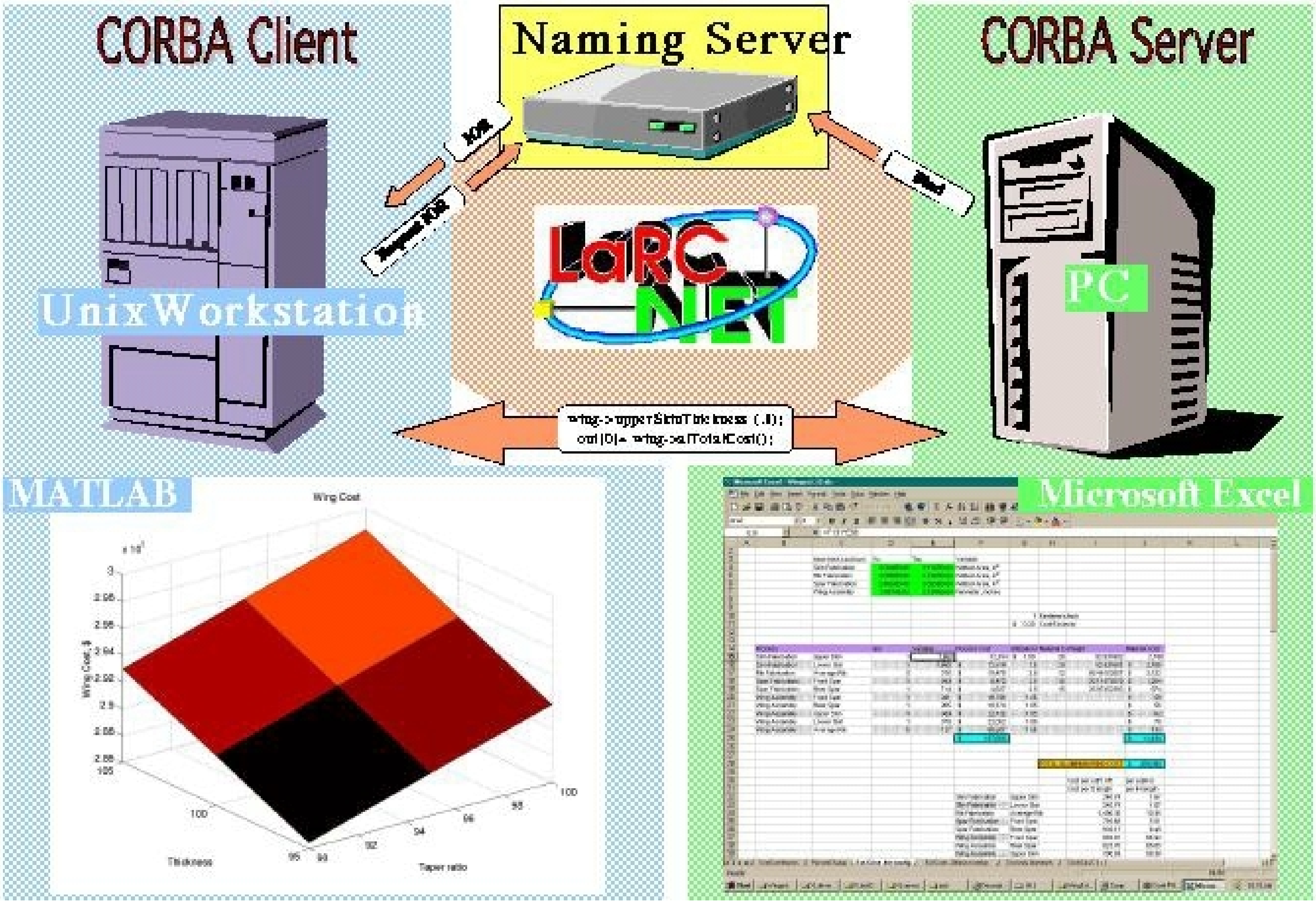
Summary

- First Order Velocity Model appears to be a good model for the following reasons:
  - Based on physical parameters
  - Has been validated in a number of studies
  - Can be readily integrated with current automated optimization codes

Cost-Performance Integration

- Commercial cost tools are developed for the PC environment
- Traditional analysis and optimization tools are developed for the Unix environment
- CORBA has been used to interface the PC-based applications with the UNIX-based applications.

Unix to Excel Interface Using CORBA



Cost Optimization with a Genetic Algorithm

- Create and assess a large number of alternative designs rapidly and automatically
- Alternative designs provide a better understanding of the design space and can answer important questions about cost, weight, concept arrangement and layout, and ability to meet the requirements

Cost Optimization with a Genetic Algorithm

- A baseline structural model for a conceptual wing design was created
  - Model contains 7 design variables representing planform and section design variables
  - Optimization problem seeks to minimize the wing manufacturing cost subject to 3 geometric constraints such as the total wetted surface area
  - Optimization problem is solved with a genetic algorithm (GA), implemented with the commercial add-in Evolver® attached to the Microsoft® Excel spreadsheet that contains the cost data. The cost data are taken from a process-based cost model tied to the design variables.

Cost Optimization of an Aircraft Wing
Genetic Algorithms Identify Numerous Local Minima